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TITLE: VISAR: 2 1/2 MINUTES FOR DATA REDUCTION

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VISAR: 2½ Minutes for Data Reduction

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Abstract

Starting with a pair of signals obtained by electronically subtracting photodetector outputs from any VISAR, it is possible to plot velocity vs time, velocity vs distance, and distance vs time in 2½ min using an LSI-11/23 computer. This includes time for six iterations of time shift with the resulting polar plots and operator interactions. The velocity calculating algorithm and a flow chart of the computer program are presented.

Introduction

VISAR data reduction is the extraction of velocity information from signals recorded during an experimental event. A variety of data reduction systems exist that require considerable time, training, and great skill to use.

Presented here is a simple data reduction method for use on a small computer that only requires two data channels, can be learned and applied in minutes, and requires less than three minutes to run.

Although its great simplicity suggests a loss of versatility, compromised accuracy, or reduced mathematical rigor, the opposite is true. For example, the undesirable practice of taking the difference between two experimental measurements is replaced here by a sensitive nulling technique at VISAR setup. The ratio of experimental measurements, the quotient of the two signals, is then used for data reduction.

For brevity, this paper will only discuss unique features of this method. The necessary signal acquisition, calibration, and recording will be omitted.

Figure 1 is an oscilloscope photograph of a complete VISAR record suitable for data reduction using this method. Its two signals result from electronic subtraction within the two pairs of signals from a push-pull VISAR,[1] or from subtracting the monitor from each of the two data signals of a three photodetector[2] VISAR. Although the subtraction could be done after recording, this would waste one data recording channel and greatly complicate the data reduction process.

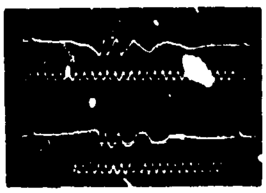

Figure 1. Complete VISAR record with two signals and their time calibration marks.

Data reduction

This data-reduction method is characterized by two unique features: a polar plot that helps diagnose signal defects and a simple angle calculating algorithm that uses the arctangent.

VISAR signal discussion

Ideally, VISAR signals are equal in amplitude and have a 90° phase difference. For this two data channel method, one signal is then like the sine of an angle; the other like the cosine. Both signals oscillate about zero.

The quotient of these ideal signals is, therefore, the tangent of an angle that is proportional to the velocity being measured. Here it is only necessary to take the arctangent, account for multiple fringes, and multiply by the fringe constant to calculate the velocity.

Although experimental data signals are not usually perfect, it is possible to detect and compensate for several common defects. Signals may be unequal in amplitude, be offset from zero, have other than 90° phase difference, or not be synchronized in time.

Polar plot

When the sines of all the angles from 0° through 360° are plotted vs their cosines, the result is, of course, a circle. This is analogous to a polar (or X-Y) plot of two ideal VISAR signals for one fringe. If the signals have equal amplitudes and differ in phase by 90°, then they will give one complete circle for each fringe.

This polar plot can be compared to the well-known Lissajous figures as used in electronics to measure the phase and amplitude relations between two signals. For VISAR signals, however, the signal amplitudes are not constant. This reduces its precision, but for signals with several fringes certain defects are clearly displayed by the polar plot.

For example, if the signals are of unequal amplitude, the polar plot will show an elliptical shape with major axis fixed vertically or horizontally. Of course, this defect is visible in the data traces also.

The polar plot will show an elliptical shape, but with an inclined axis for signals with other than a 90° phase difference. This is difficult to see except in a polar plot.

Offset zero, in either or both signals, is very easy to identify because the origin is plotted off-center. This origin is determined from the zero light levels recorded on both traces before laser turn-on.

Time synchronization errors cause an elliptical shape with a rotating axis. Plotter rotation reverses as the ellipse degenerates to a straight line.

Information displayed by the polar plot can be used in a variety of ways to eliminate the effects of signal defects. After many shots, we have developed a practical system for its use.

Corrective interactions using the polar plot

Because the amplitude ratio is easy to adjust properly in setup, and because data reduction is insensitive to modest errors in it, it is practical to estimate the correction factor by inspection of the polar plot. Similar reasoning applies to the phase difference. Thus we allow for changes in either to be input by the data analyst. Corrections here, though, are very infrequent.

Offset zero errors are corrected manually by translating the origin just after the polar plot is completed. This operator interaction is quick and simple, when needed.

Time synchronization errors are minimized by selecting the best one of six polar plots. These are plotted automatically each shot with very small relative time shifts between the two signals each iteration. When none is clearly best, the one with no intentional shift with respect to the time fiducials is picked.

Although the choice is sometimes subjective, the use of this system effectively allows more productive use of expensive data recording channels. The alternative is to use more recorders, sweeping faster, to provide better time resolution. The resulting increased cost is justified in some experiments.

Angle calculating algorithm using arctangent

Even though the arctangent can be used directly with ideal signals, it is much more practical to use equation (1) with real signals to allow for zero offset corrections, the possibility of unequal signal amplitudes, or phase differences other than 90°.

$$V(t) = K \tan^{-1} \left[K_1 \frac{(D2(t)-X)}{(D1(t)-Y)} \frac{1}{\sin\beta} - \cot\beta \right]_0^t \tag{1}$$

Here $V(t)$ is the velocity at time t, K is the fringe constant in velocity/angle, K_1 is the amplitude ratio of the two signals, $D1(t)$ and $D2(t)$ are the signal values at time t, X and Y are the zero offset corrections, and β is the phase difference.

Observe that this equation complements use of the polar plot. Origin translation coordinates obtained from the polar plot, when needed, are simply subtracted from their respective signals. The polar plot provides a graphic measurement of the amplitude ratio, K_1, used in this equation. Any departure from the ideal value of 1.0 can be input by the operator. Similarly, the polar plot displays and facilitates corrections of the phase difference, β. Thus, all constants needed for calculating velocity can be checked, and usually corrected if necessary, using the polar plot.

The remaining unknowns are simply the two signals $D1(t)$ and $D2(t)$. Velocity calculations repetetively use the arctangent in a computer algorithm for each instant in time where data are taken.

It is possible to simplify the algorithm by a rearrangement of the terms of equation (1):

$$\frac{V(t)}{K} = \tan^{-1} \left. \frac{K_1(D2(t)-X) - (D1(t)-Y)\cos\beta}{(D1(t)-Y)\sin\beta} \right|_{o}^{t} \tag{2}$$

To facilitate computer calculations with discrete time steps, it is convenient to replace the times, t, by array subscripts, I, representing integers counting each data point recorded. Time data are in another array with matching subscripts.

$$\frac{V(I)}{K} = \tan^{-1} \left. \frac{K_1\ (D2(I)-X) - (D1(I)-Y)\ \cos\beta}{(D1(I)-Y)\ \sin\beta} \right|_{o}^{I} \tag{3}$$

Here the numerator and denominator can be considered similar to the sine and cosine, respectively, for the case where $\beta = 90°$.

This provides important benefits. The n x 180° ambiguity of the arctangent is increased to n x 360° (by use of the sign of the sine and cosine). Accounting for multiple, whole fringes is simplified. Thus, only one valid data point is needed for every two consecutive quadrants to properly count whole fringes, even with acceleration and deceleration!

Figure 2 shows a diagram of this algorithm. Including remarks, it takes 32 program lines to calculate and accumulate the angle from zero. It automatically accounts for multiple fringes, even with acceleration and deceleration. This includes any origin translation, amplitude ratio and phase difference corrections made. No other accounting is needed for partial fringes, peaks, valleys, etc. The velocity is simply this angle times the fringe constant.

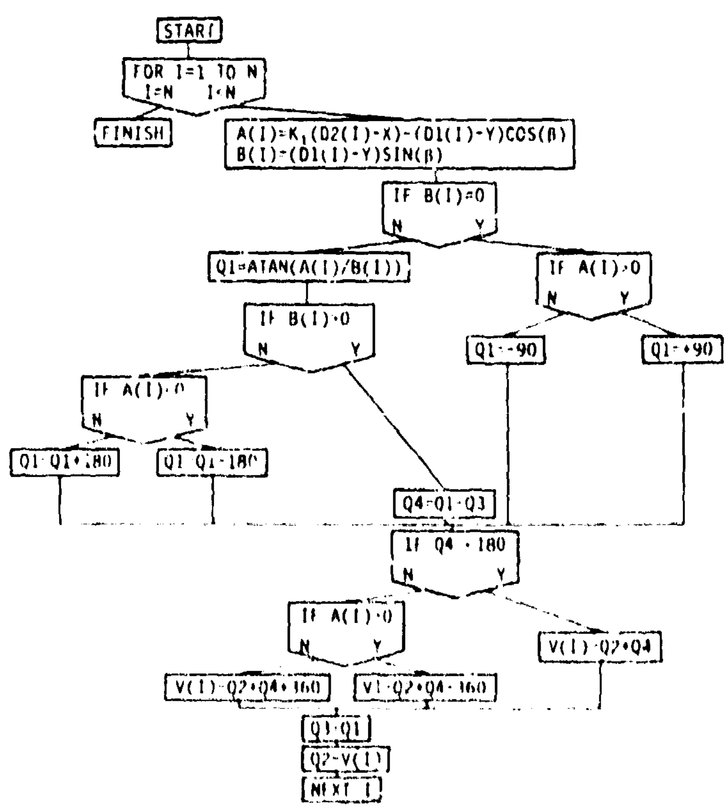

Figure 2 Diagram of VISAR angle calculating algorithm. It determines unique angle over full 360° and automatically accounts for multiple fringes, even with acceleration or deceleration.

VISAR data-reduction flow chart

The flow chart of Figure 3 is included to illustrate the overall simplicity of our data-reduction program. It is assumed that the data input for reduction consists of two time calibrated signals, with their respective zero light levels, and their early fiducials set to an arbitrary zero time.

After permitting operator selections from a menu, the program begins by making six polar plots. The operator then selects the one with no time shift, or one that displays a more circular shape.

That plot is then replotted to a large scale to permit operator translation of the origin, if necessary. The origin is initially plotted at the zero light level from the input data.

Calculation and plotting the three separate graphs then takes approximately 1 min, including velocity vs time, time vs distance, and velocity vs distance.

At this point, the operator is given a menu of choices to allow changes, fringe additions, etc. With high-quality signals, it only takes 2½ min per shot to read data from a floppy disk until the results are plotted.

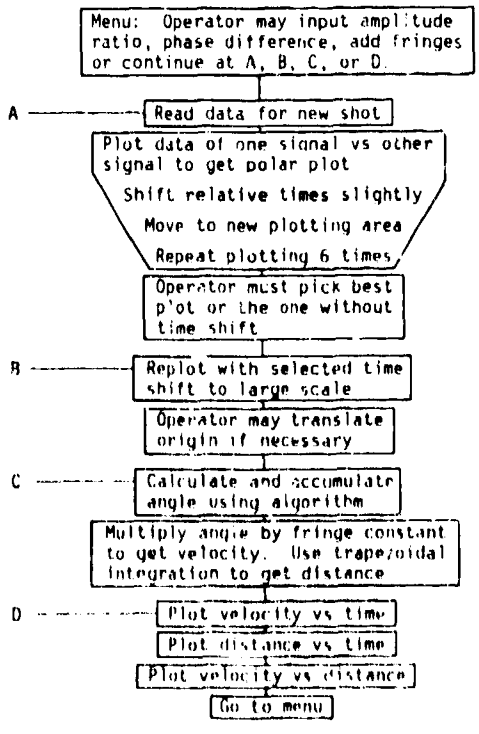

Figure 3. Flow chart of VISAR data reduction program. Its execution takes approximately 2½ min per shot on LSI-11/23 computer.

Conclusion

Starting from two VISAR signals, it is possible to calculate the velocity history and plot the results in 2½ min. Mathematical rigor, accuracy, and versatility are not sacrificed.

References

1. Hemsing, W. F., "Velocity Sensing Interferometer (VISAR) Modification," Review of Scientific Instruments, 50 (1), January 1979.
2. Amery, B. T., "Wide Range Velocity Interferometer," Sixth Symposium on Detonation (Office of Naval Research, Department of the Navy, Arlington, VA, 1976), p. 215. August 24-27, 1976.